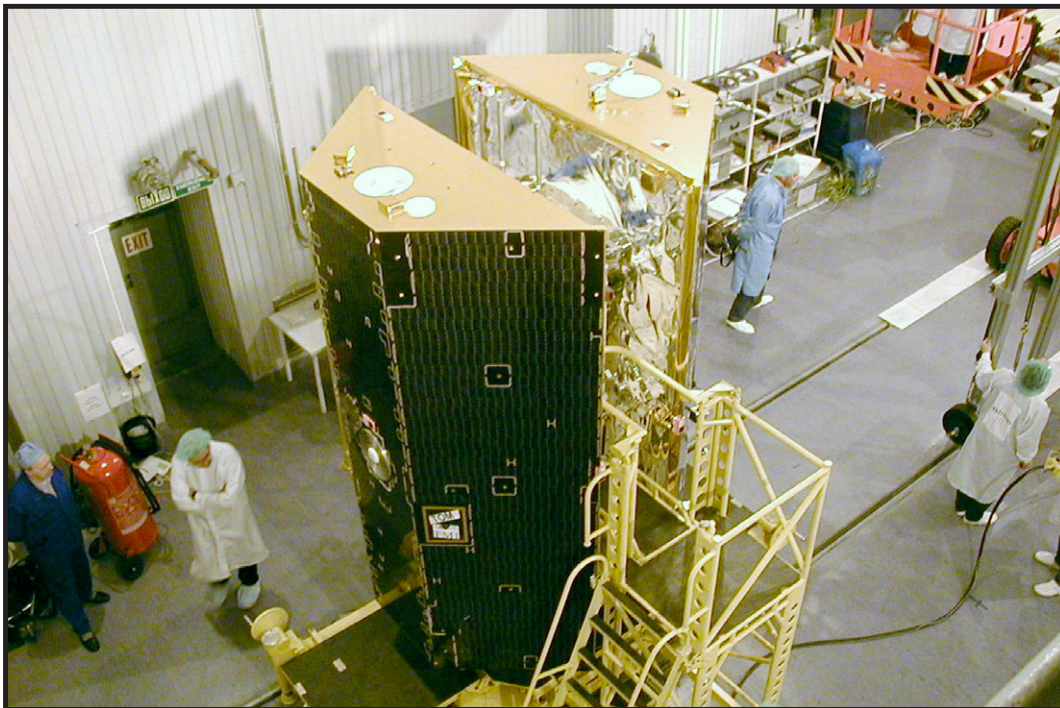
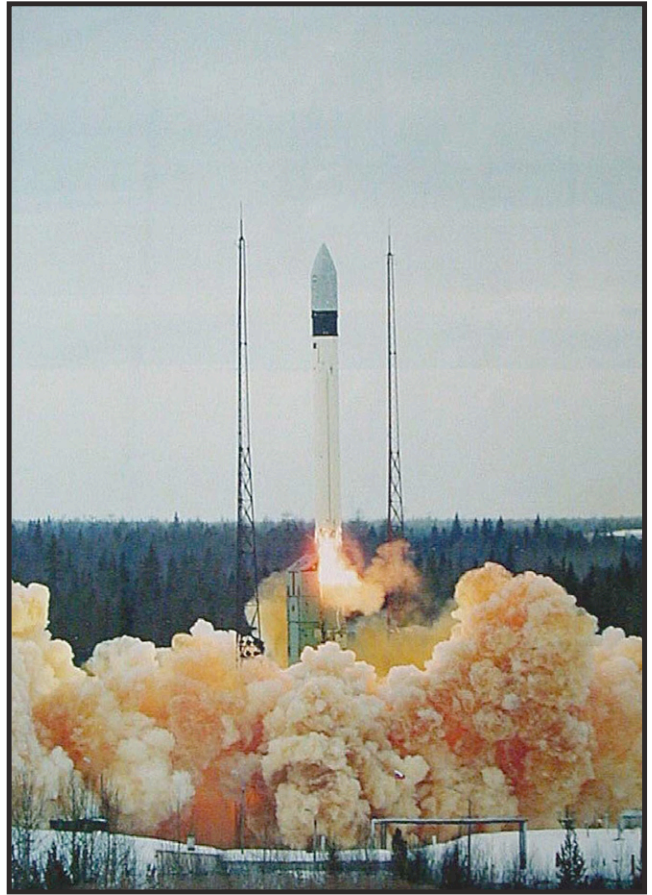


Gravity Recovery and Climate Experiment

The GRACE mission consists of two identical spacecrafts flying in the same orbit, about 220 kilometers apart at a height of approximately 500 km. The pair, unofficially nicknamed “Tom and Jerry”, orbit the Earth in about 95 minutes. The mission began on March 17, 2002 from the Plesetsk Cosmodrome in Russia. While the experiment was planned to last 5 years, it is still going strong after 7 years, providing valuable data for Earth sciences.

The concept that gravity is not constant, that it changes with location and in time as the mass distribution of the Earth changes, is well known to scientists, but was generally unfamiliar to students and the general public - until now. As GRACE has mapped the Earth's gravity field and its variations from month to month, the results describing our dynamic Earth system are making headlines. The changes in the ice sheets and glaciers in Antarctica, Greenland, Alaska and South America are among the most notable observations. Tiny changes in the Earth's gravity – due mostly to the movement of water around the planet – are critical for making predictions about the Earth's climate. These precise gravity field measurements, combined with other satellite and in situ (ground) measurements, underpin a large variety of climate-change-related studies in oceanography, hydrology, glaciology, and solid-Earth sciences.

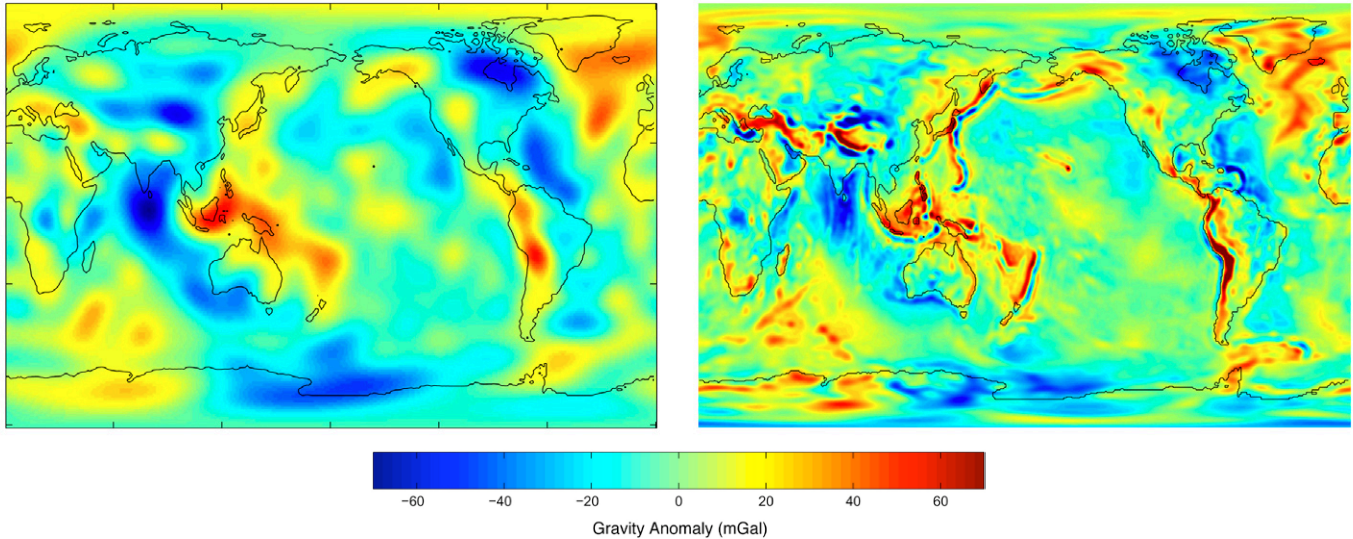


The GRACE spacecraft, unofficially nicknamed “Tom and Jerry”

Why is GRACE Special

GRACE is measuring gravity at an UNPRECEDENTED level of precision and resolution. The dramatically improved map of the mean Earth gravity field helps to refine our knowledge of the composition and structure of the Earth, and it provides the accurate reference surface relative to which deep ocean currents can be determined.

The changes are given in milligal. A milligal is a convenient unit for describing variations in gravity over the surface of the Earth. 1 milligal (or mGal) = 0.00001 m/s², which can be compared to the total gravity on the Earth's surface of approximately 9.8 m/s². Thus, a milligal is about 1 millionth of the standard acceleration on the Earth's surface. On the front panel the changes after the Sumatra-Andaman earthquake are measured in microgal, which is thousand times smaller than the milligal.



Best global gravity map from decades of satellite data before GRACE

Gravity map from four years of GRACE only data

GRACE is UNIQUE, as it gives a global, consistent and uniform quality measurement of mass flux (movement of material around and within the Earth), observing geophysical processes within every one of the Earth's sub-systems (land, ocean, atmosphere, terrestrial water storage and ice sheets). *See Greenland and Sumatra-Andaman on front*

Of particular interest for understanding the Earth's climate system, **GRACE MONITORS** the movement of water over the Earth's surface with a level of detail never seen before. *See Amazon on front*

GRACE spans ALL of geosciences; the results address questions within the "Climate/Variability", "Water Cycle" and "Earth Surface & Interior" focus areas of NASA's Earth science priorities.

The measurements **GRACE** is providing from Earth orbit would be impossibly expensive if they were done on the ground - **THERE IS NO SUBSTITUTE** for observing the whole Earth from Space.

GRACE is a joint project of the American space agency NASA, the German Aerospace Center (DLR), the University of Texas Center for Space Research (CSR), GeoForschungsZentrum Potsdam (GFZ) and the Jet Propulsion Laboratory.

EXPLANATION OF FRONT PANELS

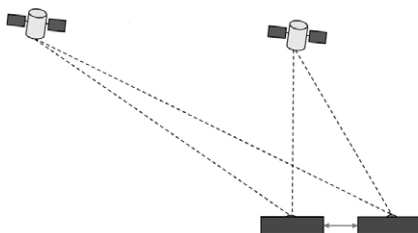
AMAZON: The amount of water stored in the Amazon basin changes with the seasons. When scientists discuss the gravity field and shape of the Earth, they often do so in terms of a surface called the geoid. It is the level surface that approximates sea level in the absence of disturbing forces. An increase in the geoid height indicates an increase in mass; a decrease in the geoid height indicates less mass. The red colors in the images show the increased gravity due to surplus of water storage in the rainy seasons; and the blue colors show the reduced gravity in the dry seasons. Thus the changing colors represent the influence of seasonal weather and climate variations. Measuring total water storage at such continental scales is impossible from ground measurements. The amount of water stored in the Amazon basin changes with the seasons. When scientists discuss the gravity field and shape of the Earth, they often do so in terms of a surface called the geoid. It is the level surface that approximates sea level in the absence of disturbing forces. An increase in the geoid height indicates an increase in mass; a decrease in the geoid height indicates less mass. The red colors in the images show the increased gravity due to surplus of water storage in the rainy seasons; and the blue colors show the reduced gravity in the dry seasons. Thus the changing colors represent the influence of seasonal weather and climate variations. Measuring total water storage at such continental scales is impossible from ground measurements.

GREENLAND: As the ice melts from the edges of the Greenland ice-sheet, the gravitational attraction from the Greenland land-mass decreases, and this is sensed by GRACE. The red color shows area of loss. The measurements in 2008 show a considerably lesser mass in South-East and Western Greenland than was present in 2003. The mass of the Greenland ice sheet acts as a very sensitive barometer of the nature of present day climate variability.

SUMATRA: For mitigation of consequences of an earthquake, it is important to understand the dynamics and changes in the local crustal structure that accompanies an earthquake. In addition to the conventional methods of seismology and surface deformation measurements, gravity changes have proven to be an unexpectedly valuable source of information. GRACE data clearly show the changes to the Earth's gravity field in the Sumatra-Andaman region due to the SA Earthquake of 2004.

How GRACE Works

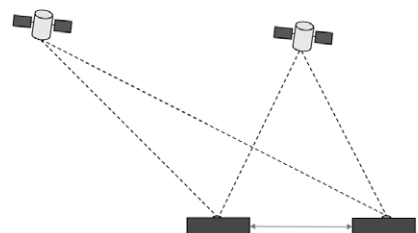
GPS SATELLITES



1 Ranging system measures distance change between the twin satellites

MASS ANOMALY
(fixed or moving "lump")

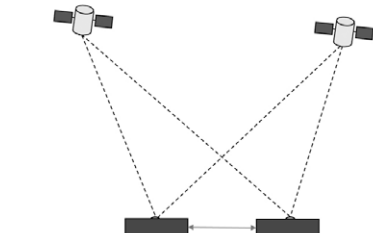
GPS SATELLITES



2 The leading satellite - being closer to the anomaly - feels a greater gravitational attraction, thus moves away from the trailing satellite

MASS ANOMALY
(fixed or moving "lump")

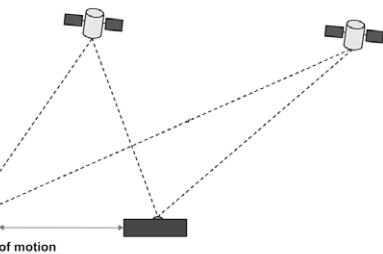
GPS SATELLITES



3 Now the trailing satellite, getting closer, is also accelerated by mass anomaly, thus catches up to the leading satellite

MASS ANOMALY
(fixed or moving "lump")

GPS SATELLITES



4 The leading satellite is far from the anomaly, and is not affected by it; while the trailing satellite - having just passed the anomaly - is being tugged backwards, increasing separation

MASS ANOMALY
(fixed or moving "lump")

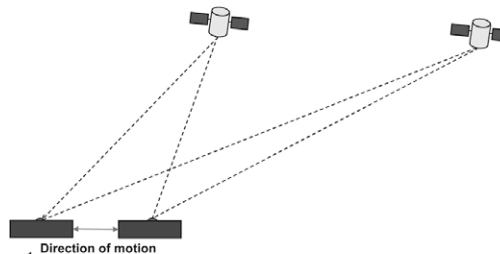
GRACE is different from most Earth Observing satellites. Rather than imaging the Earth, it detects gravity changes by measuring the distance between the satellites themselves. But how does this distance measurement relate to gravity?

The gravity field of a body depends on its mass and shape. For a perfectly spherical and uniform body, the gravity field is simple and symmetric in any direction. The mass distribution of our planet, however, is irregular and 'lumpy'. Molten rock flows in the Earth's mantle to drive tectonic plate motion, enormous quantities of water are exchanged between the ocean and land, and atmospheric masses are also in continuous movement.

As the satellites move through this uneven gravity field, the orbits of each satellite are slightly disturbed, which affects the distance between the two spacecraft. GRACE's uniquely precise microwave ranging system measures changes in the approximately 220 km distance between the satellites with an accuracy of some microns – about one-tenth the width of a human hair!

In addition to measuring the distance between each other, the satellites use the GPS system to determine precisely where and when the measurements were taken. The ultra-precise measurements taken by GRACE, combined with tracking data from the GPS satellites, allows scientists to map the Earth's gravity field with unprecedented accuracy.






































GPS SATELLITES



5 The trailing satellite catches back up with leading satellite but the 'signature' of mass 'lump' has been captured as a sequence of changing disturbances

MASS ANOMALY
(fixed or moving "lump")

Aligning with Standards

NCES Standards	ACTIVITY & GRADE LEVEL						
	Poster		On the Web				
	Colony Ship	Greenland Ice loss	Blinded by Water vapor	As the Waters Warm	Grace by the Numbers	Finding Your Center of Mass	Remote Sensing of Gravity Fields
	6-12	7-12	3-5	6-8	6-8	9-12	9-12
Science as Inquiry - Abilities Necessary to Do Scientific Inquiry – Process of Scientific Inquiry							
Physical Science - Properties and Changes in Matter – Motions and Forces – Transfer of Energy							
Earth and Space Science - Structure of the Earth System – Earth's History – Solar System							
Science and Technology - Technological Design – Science and Technology							
Science in Personal and Social Perspectives - Role of Science and Technology in Society							
History and Nature of Science - Science is a Human Endeavor, History of Science, Nature of Science							
NCTM Standards	Colony Ship	Greenland Ice loss	Blinded by Water vapor	As the Waters Warm	Grace by the Numbers	Finding Your Center of Mass	Remote Sensing of Gravity Fields
Geometry							
Measurement							
Data Analysis and Probability							
STL Standards	Colony Ship	Greenland Ice loss	Blinded by Water vapor	As the Waters Warm	Grace by the Numbers	Finding Your Center of Mass	Remote Sensing of Gravity Fields
Nature of Technology - Standards 1, 2, 3							
Design - Standards 8, 9 10							
Abilities for a Technological World - Standard 11							

The following activities can be downloaded from http://www.csr.utexas.edu/grace/GRACE_Edu_Poster/

Blinded by Water Vapor
As the Waters Warm
GRACE by the Numbers
Finding Your Center of Mass
Remote Sensing of Gravity Fields (Simulation)

More information is available at:

<http://www.csr.utexas.edu/grace/>

<http://grace.jpl.nasa.gov/>

<http://earthobservatory.nasa.gov/Features/GRACE/>

http://op.gfz-potsdam.de/grace/index_GRACE.html

ACTIVITY - GREENLAND 2008

Estimating Mass of Ice Lost from Greenland between 2003 and 2008

In this activity, the student interprets contour maps in order to estimate the amount of ice lost from Greenland. The student needs to approximate the volume of irregular based prisms, and, from that, to calculate mass from density and volume.

Background: Tiny changes in gravity can be important clues to understanding fluctuations in the amount of water stored above and below ground. In the Arctic, where the above-ground water is frozen, GRACE has found that the ice sheet that covers most of Greenland is shrinking. Measurements of decreasing gravity over the ice sheet indicate a decrease in the ice sheet's mass. The melting Greenland ice sheet contributes about 0.3 millimeters per year to a rising global sea level. GRACE continues its measurements to understand whether this rate of sea level rise is increasing or decreasing.

Teacher: Discuss what happens to the sea level when a floating iceberg melts, what happens when a land-based glacier melts, and which has an affect on the sea level. Let the students examine the Greenland contour maps on the back. Ask them to explain in their own words what the contour map tells us. (Note, all the changes are calculated from the 2003 state of the ice sheet. Not all the changes are negative; some locations gained mass, thus accumulated more ice. The students need to consider this for the total change.)

Ask students:

1. How can we estimate the amount of mass change between the years 2003 and 2008 if we know how much the height of the ice sheet (more precisely, the height of the equivalent amount of water) changed?

Answer: We need to find the total volume change, then use the density of water to calculate the mass.

2. How can we find the volume of an irregular shape?

Answer: Imagine replacing the original shape with many small, square-based rectangular prisms packed next to each other. Add up the volume of the individual prisms to get the total. Counting will be simpler if the different intervals are colored with contrasting colors before laying the grid over.

3. Between two contour lines, the heights of the prisms should all be the same. Which number represents the height: the value of the smaller, the larger contour height, or their average?

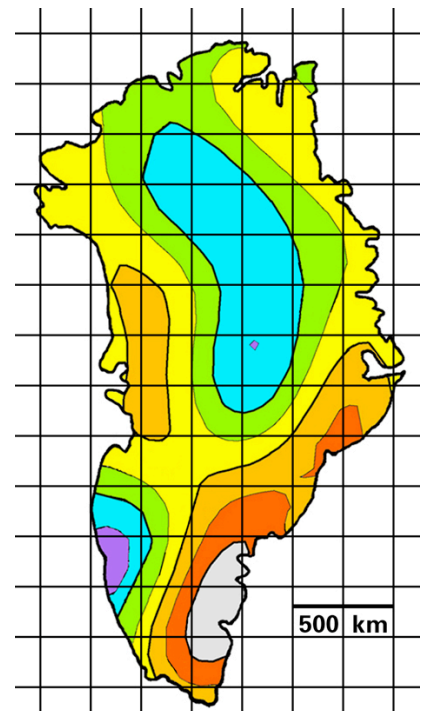
Answer: Using the lower value underestimates the volume, the larger overestimates it, the average is likely to be closest to the real value.

4. What do you do about squares that is divided by a contour line?

A reasonable solution: count the ones which are colored halfway or more with the color you are counting, ignore the rest. Can you think of other counting strategies?

5. How does the size of the grid effect the results?

Answer: The grid with smaller squares will approximate the area better. However, it increases the chance of miscounting the squares.



Example of colored contour map with a 250 km grid overlay

ACTIVITY - GREENLAND 2008

Estimating Mass of Ice Lost from Greenland between 2003 and 2008

After the students counted the squares for all the different ice loss intervals, they need to figure out the area covered by those squares. It is simply the number of squares times the area of one square.

The volume of a rectangular prism: **Volume = Area x Height**,
the shape of the area does not matter as long as the cross section is the same all the way.

The mass of the prism of ice can be calculated by: **Mass = Volume x Density**

Since the amount of ice lost is given as the equivalent amount of water, the student can use 1g/cm^3 to calculate the mass. (Note the length units are not consistent, the grid units are in km, the ice height is in cm, so make sure you convert both to meters, to work with SI units.)

Ask students to calculate the mass change from 2003 to 2008. What does a negative change mean? (Mass loss)

Answer: (using the average value between contours)

$$\text{Mass difference (2008-2003)} = -7.43 \times 10^{14} \text{ kg} = -743,000,000,000 \text{ ton}$$

This number is only one possible estimate, calculated with a particular choice of grid. However, for all reasonable grid sizes, the order of magnitude should be the same.

The answers between students, or students groups will differ depending on the grid placement, how they counted the partially filled squares, or simple arithmetic errors. Ask the students to compare their results, and if it is possible to determine a single correct result or is there some range to the possible results.

Suggestions for the teacher:

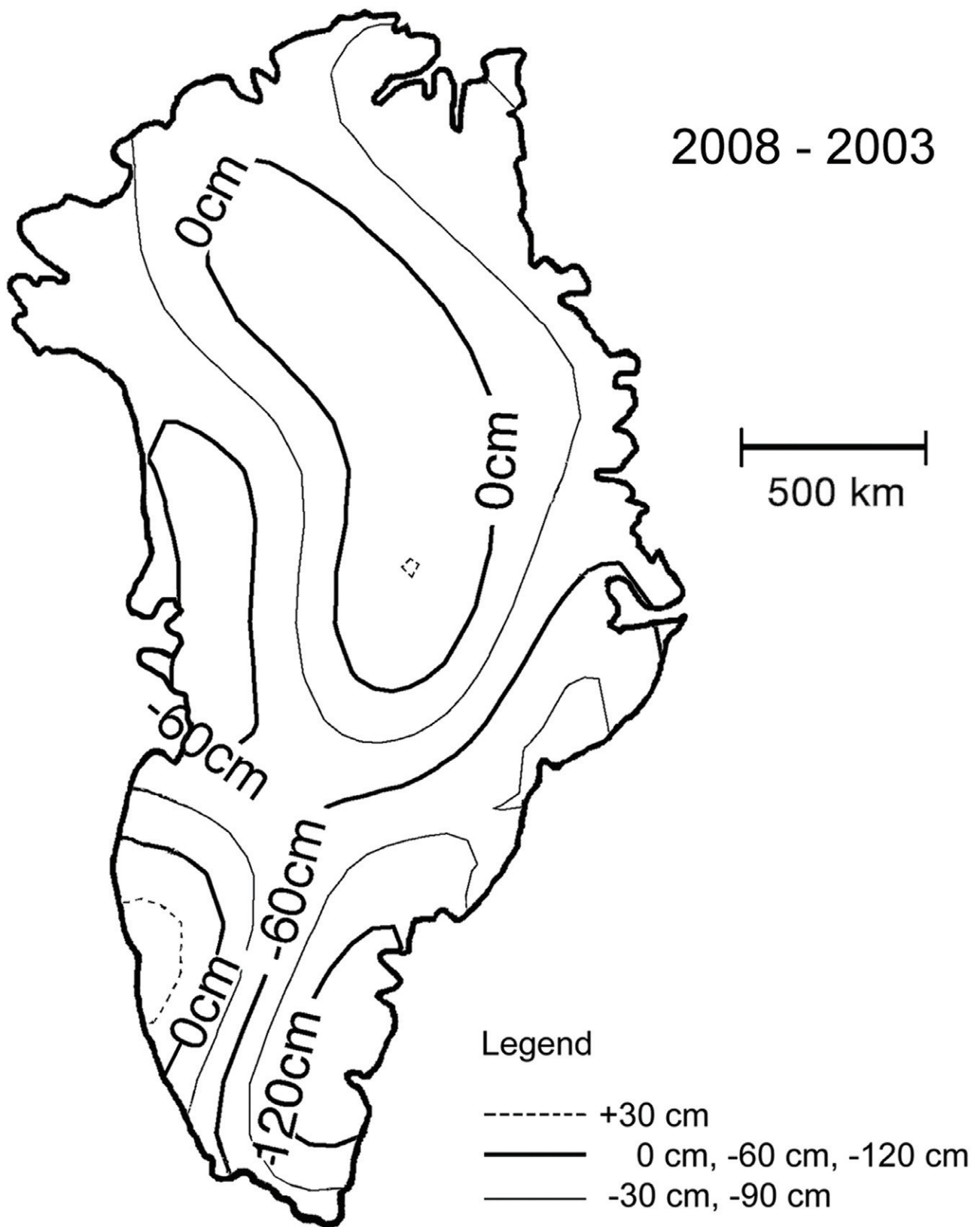
- Before calculating the mass ask students to add up the number of all color squares. Should that number differ for the different years?

Answer: No, it always should add up to about the same, the area of Greenland. (The number of squares depends on the grid size they choose.)

- If more than two answers have the same order of magnitude, they probably got it right; it is unlikely the different groups made the same mistake. If we exclude the obviously different ones, how can we improve the estimates? (The average of the results for a year is likely to be closer to the real value, than the individual numbers).
- If the results are wildly different, it is best to repeat the exercise using larger copies or a different grid.

Additional contour maps can be downloaded from
http://www.csr.utexas.edu/grace/GRACE_Edu_Poster/

Estimating Mass of Ice Lost from Greenland between 2003 and 2008



ACTIVITY - DESIGNING A COLONY SHIP

Designing a Colony Ship: A Thought Experiment

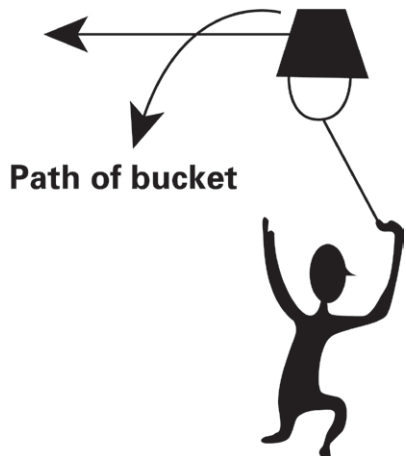
Congratulations! You have been selected to design the very first colony ship to go to Mars. The ship needs to carry a hundred people for the eight-month journey from Earth. The doctors at NASA tell you that you cannot leave people in zero gravity for so long, their bones may become too weak to support them once they land. You have to make gravity onboard your ship. However, this isn't Star Trek and you don't have any "gravity plates".

What can you do? Here are some hints to get you started.

- Try this little experiment outside. Get a small pail with some rope tied to its handle. Fill it less than halfway. If you just turn the pail upside-down, all the water will fall out. But, what happens when you swing a bucket of water in horizontal circles? Look at the surface of the water.
- Now try this: hold the bucket out to your side and spin it quickly in a vertical circle. If you move it fast enough, the water will stay in the bucket, even when the bucket is upside-down or sideways! (It might take a little practice.)
- Now, imagine that instead of water, there are tiny people in the circling bucket holding small books. What direction would the books fall if they were just let go? Would they fall towards the bottom of the bucket, or toward the top? Whatever way the books fall is the direction of the artificial "gravity" that they feel.

How the bucket trick works:

**Path of water
without the bucket**



The water stays in your bucket, because whenever you spin something, you always need to pull it toward the point you're spinning it about. Otherwise it would continue in the direction of its original velocity. You pull the pail inwards, so the water in it gets pushed in, against its bottom. Gravity always pulls the water down, but your spinning keeps the water moving around the center. If you spin the bucket at the right speed, the water stays in place with respect to the bucket, even when it's upside down.

Do you have a design idea now? Read on for one possible answer:

The simplest way we know to make artificial gravity is to spin the ship. The spinning will cause everything to fall toward the outer hull of the ship, acting like gravity, which makes the NASA doctors and the colonists happy since the food will not float away when they eat!

Here are a few more things to think about when designing your colony ship:

- How can you control the strength of the artificial gravity? (The faster the spin, the stronger the gravity will be.)
- What should be the shape of your ship? Does it matter, in terms of the artificial gravity system? (Hint: we want gravity to act as uniform as possible for everyday life on the ship.)
- Where will the artificial gravity be strongest in your ship? Where will it be the weakest? Why? (Hint: If you get dizzy on a playground merry go round, where would you stand to avoid the problem?)
- Imagine that your ship is hollow and you stand on one side of the inside. You'd be held by the artificial gravity, so everything would seem normal. Then imagine you asked a friend to go stand on the far side of the ship. He'd appear upside-down to you! Why wouldn't he fall? (Hint: think about Australians.)

There are many other questions to think about when designing an artificial gravity system for a space ship. For example:

How fast should the ship spin?

Where do you put your communications antenna, which always needs to point to the Earth, even when your ship is spinning?

Will the colonists feel any sideways motion from the spinning, or will it all be "down" to the edges of the ship?